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Conditions Favoring the Reduction of Pesticides: A Qualitative Comparative Analysis of EU Member States

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ABSTRACT

Pesticide use in agricultural production presents a significant sustainability challenge, balancing crop protection against environmental and health risks. While the EU pro-vides a common regulatory framework, the implementation in the member states varies considerably. By means of a fsQCA we investigate the conditions for implementation success of pesticide reduction policies. Building on recent literature on differentiated policy implementation (DPI) in the EU, we examine the role of political parties, interest groups, and public salience. Our findings reveal four distinct pathways to successful pol-icy implementation: (1) high public concern and green representation in parliament compensating for weak lobbying, (2) high-capacity interest groups exploiting high pub-lic concern even in unfavorable political climates, (3) coalitions of interest groups, green parliamentarians, and public concern driving implementation, and (4) high-capacity interest groups compensating for low public and political support. We thereby contrib-ute to an improved understanding of EU environmental policy implementation.

1 | Introduction

Pesticides are a frequently discussed topic in sustainability debates. Employed to increase production by "protect[ing] crops and yield from unwanted infestation" (Wiedemann et al. 2022, 155), a plethora of research shows that pesticides do not only harm honey bees (Motta et al. 2018), frogs (Hayes et al. 2010), or aquatic and terrestrial ecosystems (Stehle and Schulz 2015), but also human beings (Larsen and Noack 2017). Yet, pesticides remain frequently used in agricultural production worldwide, with currently almost two-thirds of global agricultural land at risk of being polluted (Tang et al. 2021).

In the European Union (EU), with 322,000 tons sold in 2022, pesticides continue to be widespread. This number stands in stark contrast with the EU's role as a global model and standard-setter for pesticide reduction policies (Möhring et al. 2020). Indeed, already in 2009, the EU adopted the so-called Sustainable Use Directive (SUD), a directive that encourages its member states to reduce the use of pesticides in their domestic agricultural sectors. The directive, however, allows significant flexibility in how member states achieve these reductions, resulting in varied national implementations (Princen and Van Dam 2023). While the EU provides a common framework, the diverse strategies adopted by member states underline the importance of understanding the domestic configurations that are conducive to policy implementation success. The recent decision to abandon the proposed regulation to transform the SUD into binding targets, due to substantial opposition from the agrochemical industry, further underscores the complexity of EU policy-making in this area. This situation illustrates the differentiated approach member states take in implementing EU directives. In light of this, it is crucial to investigate how pesticide reduction strategies are applied differently across member

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states, influenced by various domestic political dynamics and institutional capacities.

Given this differentiated landscape, the lens of differentiated policy implementation (DPI) becomes particularly relevant. DPI is a novel framework that includes both compliant and non-compliant transpositions of EU policies to the member state levels. Importantly, DPI moves beyond the existing compliant literature by highlighting that, also within compliant transpositions, a great diversity may exist among member states—so-called "customization". Customization allows member states to take into account their national contexts when integrating EU law into their own legal systems. The DPI approach allows us to explore how member states transpose and apply EU legislation, taking into account the flexibility and discretion they are afforded. This approach is valuable in analyzing the variance in pesticide reduction efforts across the EU, highlighting the interplay between EU-level directives and national-level implementation strategies. In this vein, this article tackles the following research question: What conditions favor the reduction of pesticides in EU member states and the successful implementation of existing EU demands in this policy area?

To answer our research question, we build on recent literature investigating differentiated policy implementation in the EU (Zhelyazkova et al. 2023). We complement this perspective by examining the role of political conditions, including political parties in parliament, the number of interest groups, and public salience. As we do not expect such conditions to operate in isolation but rather that they may boost or hinder each other in combination, we rely on a method that allows for causal configurations—namely, fuzzy-set Qualitative Comparative Analysis (fsQCA). fsQCA is a methodology based on set theory, which allows for the comparison of middle-N case numbers (Schneider and Wagemann 2012). The dataset is based on a compilation of different sources such as Eurobarometer and the European Union's Transparency Register.

Our main findings, constituting four different paths to achieving successful pesticide reduction policy implementation, can be summarized as follows: Firstly, mobilizing public opinion and making use of green political representation can compensate for weak lobbying to drive policy changes. Secondly, high-capacity interest groups can exploit high public concern to push policy implementation even in less favorable political climates, underscoring their influential role. Thirdly, building coalitions among interest groups, green parliamentarians, and the public creates powerful advocacy for successful policy implementation. Fourthly, even under conditions of low public and political support, strong and numerous interest groups can lead to policy change—a fact that highlights the critical role of well-resourced lobbying efforts in policy-making.

The article is structured as follows. Section 2 elaborates on pesticide policies in the EU. In Section 3, we introduce the literature on differentiated policy implementation and present our theoretical contribution. Section 4 presents our data and the QCA method. Section 5 describes the findings of the analysis, which are subsequently discussed. Section 6 comprises concluding remarks and avenues for future research.

2 | Pesticide Policies in the EU

In the following, we provide an overview of pesticide governance in the European Union (EU) and recent developments that are relevant to our case. Authorization of pesticides is shared among governance levels in the EU, with the European Food Safety Authority (EFSA) evaluating active substances that are used in pesticides, and the member states evaluating and authorizing pesticide products for their national markets. These procedures are regulated in Regulation (EC) No. 1107/2009.[1] Furthermore, maximum residue levels of pesticides in food and feed are set by Regulation (EC) No. 396/2005.[2]

In 2009, the so-called Sustainable Use Directive (SUD),[3] which is at the center of our analysis, was adopted. The goal of this Directive is the risk and impact reduction of pesticide use via the promotion of Integrated Pest Management and alternatives to pesticides. Importantly, this directive gives member states the freedom to choose their own reduction targets; there are no binding targets for all member states. The member states have installed National Action Plans (NAPs) to implement the SD, which are regularly updated. Additionally, the European Commission has accompanied the Directive's implementation with an evaluation of the NAPs in 2017 and with a report on the Member States' implementation experiences in 2020.

In 2017, the European Citizens Initiative (ECIs) "Ban glyphosate and protect people and the environment from toxic pesticides" collected over a million signatures across the EU. Calling for a ban on the pesticide glyphosate, for a reform of the pesticide approval procedure, and for mandatory reduction targets for pesticide use across the EU, it is one of only 10 successful ECIs since the launch of this instrument in 2012. This ECI created momentum for more ambitious pesticide reduction policies in the EU. As a part of the Farm to Fork Strategy in 2020, the European Commission communicated the goals of reducing the use and risk of chemical pesticides by 50% and reducing the use of more hazardous pesticides by 50%, both by 2030. Also, in 2022, the European Commission published a proposal for a new Regulation on the Sustainable Use of Plant Protection Products, which would have transformed the above-mentioned SUD into a regulation with the 50% reduction targets becoming binding for all EU member states. However, the proposal was withdrawn again in March 2024, as the European Parliament had rejected the proposal and as there was a "lack of progress in the discussions in the Council". Thus, the SUD remains in place, with member states defining their own reduction targets in the NAPs. In light of this policy failure, scientists have emphasized the urgent need for "a holistic transformation of agricultural systems and practices [...], including large-scale substitution of potentially harmful pesticides with more sustainable pest management practices" (Finger and Möhring 2024).

3 | Differentiated Policy Implementation in the European Union

Theoretically, our study builds on the literature on compliance and the implementation of EU requirements in member states, which highlights variations in both timing and quality of implementation

(Clinton and Arregui 2024; Thomson et al. 2020; Zhelyazkova and Thomann 2022; Börzel and Buzogány 2020; Heidbreder 2019). While directives may be successfully transposed into national legislation, practical implementation often remains challenging (Versluis 2007). Key explanations for compliance include implementers' preferences and the capacities of implementing agencies (Thomson et al. 2020). Additional research emphasizes the role of stakeholders in the transposition process and the difficulties national governments face in reconciling diverse interests when implementing EU law (Kaya 2018). Most of this literature focuses on member state-level factors as drivers of non-compliance, though some studies also highlight the European Commission's role in managing compliance (Börzel and Buzogány 2020).

A more recent and evolving strand of research examines the diverse interpretation and implementation of EU policies by national governments, referred to as *customization* or *differentiated policy implementation* (DPI) (Zgaga et al. 2024; Fink and Ruffing 2017; Zhelyazkova and Thomann 2022). Customization offers a theoretical framework that extends beyond compliance measurement by analyzing the extent to which member states adapt EU regulations during transposition (Zhelyazkova et al. 2023). Customization involves two key measures: restrictiveness and density. Restrictiveness pertains to changes in content, such as raising or lowering regulatory standards, while density refers to the quantity of regulatory measures enacted. Member states have the ability to customize EU law by making it either more stringent or more lenient (restrictiveness) and by increasing or decreasing the number of rules (density). Although these measures are often interconnected, they can also function independently (Brendler and Thomann 2024). Research into the causes of customization is still in its early stages. In an introduction to a recent special issue, Zhelyazkova et al. (2023) have synthesized the findings of existing empirical studies and coined the term differentiated policy implementation, which encompasses both compliant adaptations (customization) and non-compliant adaptations. Against this background, differentiated policy implementation refers to the varying degree and manner in which national governments adapt or deviate from EU rules during the transposition and implementation process, which could involve both compliant and non-compliant actions.

As the policy we focus on comes in the form of a directive (Pesticide Directive 2009/128/EC), the DPI literature is a particularly promising theoretical lens for the analysis. EU Directives leave major scope for action to the member state, including the choice of instruments. This flexibility can take the form of adopting more stringent standards as well as expanding or restricting the scope of the directive (Princen and Van Dam 2023). Recent work, including that by Zhelyazkova, Thomann, Ruffing, and Princen, highlights that while differentiation in policy implementation can accommodate national diversities, it also may imply negative repercussions such as policy fragmentation and reduced policy coherence across the EU. DPI involves not only the adoption of these policies but also the extent and manner of their enforcement and execution at the national level. DPI acknowledges that while the EU provides a common framework, the practical application of these policies can differ significantly across countries.

As the research agenda on DPI is still emerging, empirical studies that grasp the complexities and implications of DPI on EU policymaking are still scarce. However, gaining a better understanding of DPI is essential for appreciating how EU policies are adapted to fit diverse national contexts, and for addressing the challenges that arise from such differentiation. As of now, there is only a limited number of empirical studies addressing the causes and drivers of DPI and the variation across regions (see, for example, the studies by Brendler and Thomann 2023, Pircher et al. 2024, and Pollex and Ruffing 2023). In this evolving strand of research five main drivers of DPI have been proposed: the level of discretion or flexibility the EU policy offers, the alignment with existing domestic policies and institutional fit, domestic political dynamics and power structures, functional drivers such as problem pressure and cooperation needs, and administrative capacity, which encompasses varying implementation costs (Zhelyazkova et al. 2023). The existing studies have in common that they usually focus on selected drivers, e.g., several empirical applications highlight alongside institutional factors, especially the role of domestic actors in the adoption of EU rules at the national level. In addition to the role of domestic actors, salience has been found to be another potential driver for differences in implementation (Brendler and Thomann 2023; Pircher et al. 2024). We tie in with these findings by testing a combination of different political aspects in order to explain differences in national implementation. In order to fully grasp domestic interests, we combine three possible explanations: public opinion (to measure issue salience), partisan politics, and interest groups' positions. We have summarized the drivers of DPI in Figure 1,

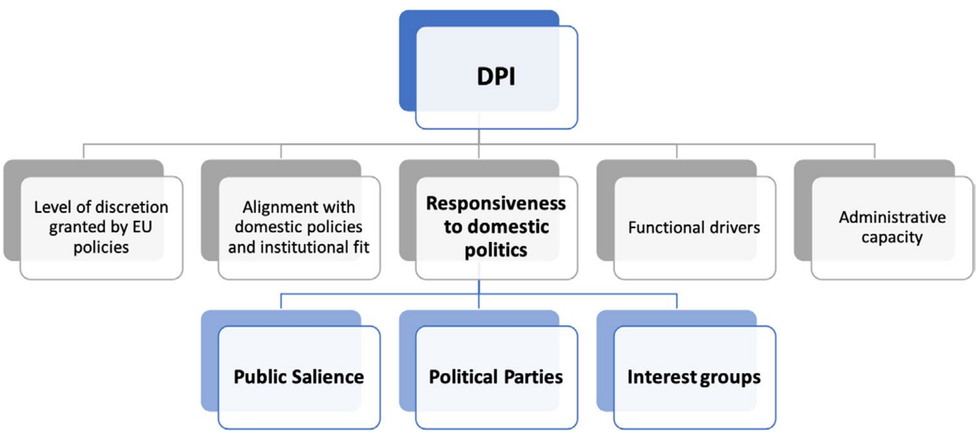

FIGURE 1 | Drivers of differentiated policy implementation. *Source:* own compilation based on the existing DPI literature.

highlighting our selected focus on the driver "responsiveness to domestic politics". The selection of one driver goes in line with the existing empirical studies. This focus on politics does not exclude the possibility that other drivers also play a role in the implementation of pesticide policies, but these cannot be fully considered in this study. Our contribution lies in detailing the political drivers and in asking how these variables (public salience, political parties, and interest groups) influence each other.

In the following, we detail our expectations regarding the selected political drivers. The literature exploring the influence of political parties on policymaking is extremely broad, but it has in common the general expectation that parties make a difference. Relevant for our case study (pesticide regulation) are two strands of research from this debate: party political positions in the area of environmental policymaking on the one hand and in the area of agricultural policymaking on the other hand. Both domains have in common that there is no uniform line of conflict, though a number of empirical studies (e.g., on voting in the European Parliament or at the national level) have tested hypotheses on the alignment of party families in both areas (for agricultural policy, see, for example Tosun 2017; Vogeler 2021; for environmental policy see for example Töller 2022; Debus and Tosun 2021). A common expectation is that green parties are more inclined towards (agri-)environmental issues, whereas conservative parties are generally more inclined towards economic and farmers' interests. For other party families, the findings are less homogenous but depend on other contextual aspects.

Party political positions are shaped by different motivations; the literature generally distinguishes between policy-seeking, vote-seeking, and office-seeking. Vote-seeking is closely connected to public preferences and public opinion regarding an issue. Depending on the national system, the inclusion of public opinion in party programs and in policymaking differs substantially. In addition, vote-seeking is often more pronounced shortly before elections. As a consequence, we argue that it is useful to include both public opinion and party politics in the analysis. Accordingly, we expect that high public concern in a member state is a second driver for DPI.

Thirdly, we include the role and strength of interest groups in the analysis. Interest groups advocate a particular interest in public and try to influence public policymaking strategically (Beyers et al. 2015), either by influencing individual decision-makers or political parties. Generally, interest group characteristics and issue-specific factors influence the success of interest groups. For EU environmental policymaking, it has been shown that diffuse interests, as they are generally articulated by environmental organizations, have a harder stance as compared to more concentrated interests such as companies (Bunea 2012). More recently, the interaction between political parties and organized interests has received increasing attention, arguing that interest groups strategically select parties with similar policy positions to push their issues in the policy process (Haugsgjerd Allern et al. 2021; Wøien Hansen and Rødland 2024). Already, the early implementation literature has pointed out the preferences of national actors on domestic implementation—an observation which has also found entry into the DPI literature (Zhelyazkova and Thomann 2022; Pircher et al. 2024). Accordingly, we include the number and strength of national interest groups in the ensuing analysis.

4 | Research Design

In this section, we detail the research design employed to investigate the conditions favoring the reduction of pesticide use among EU member states. Our analysis focuses on a subset of EU member states, utilizing fuzzy-set Qualitative Comparative Analysis (fsQCA) to explore the complex relationships underpinning policy implementation. The data sources include various European surveys, policy documents, and public registers.

We have chosen to focus on 14 countries that became members of the EU prior to 2004.[4] This is due to several reasons. Firstly, these 14 pre-2004 countries have a longer history of EU membership, providing a consistent and extensive period of exposure to EU pesticide reduction policies. This allows for the analysis of long-term impacts and trends in policy implementation. Secondly, these countries share more comparable institutional frameworks and administrative capacities due to their established integration into the EU, which facilitates a more coherent and systematic comparative analysis. By focusing on these countries, we reduce the heterogeneity that might arise from including newer member states with different levels of alignment and adaptation to EU directives. This homogeneity aligns well with the fsQCA methodology, enabling us to identify distinct pathways and conditions that influence policy success or failure within a relatively stable and comparable group. Additionally, the maturity of policy environments in the 14 EU member states provides richer data and allows for the exploration of more developed domestic responses to EU directives, contributing to a clearer understanding of the conditions conducive to effective pesticide reduction.

We do not include the United Kingdom in our examination due to its departure from the EU in 2020. Moreover, we decided to exclude the case of Belgium from the final analysis because various challenges arose during data collection that called the reliability of the data into question. With 182 interest groups employing 675.2 FTEs, the number of these was much higher than in all other countries, which can only be explained by the presence of lobby groups in Brussels, which do not relate to the national situation. Separating these groups has proven to be empirically untenable, which is why we decided to exclude the country from the analysis. The share of agricultural production in relation to the country's GDP is also among the lowest in Europe; accordingly, the case is per se of minor relevance for the purpose of the study.

We employ fsQCA, a method grounded in set theory and specifically designed to address complex research questions involving multiple causal conditions (Schneider and Wagemann 2012; Ragin 2014). This methodology is particularly well-suited for our study for several reasons (Bazzan et al. 2022; Berg-Schlosser et al. 2009; Engeli et al. 2014). Firstly, fsQCA enables systematic cross-national comparisons, allowing us to analyze conditions in an intermediate N-design. This means we can effectively handle the diversity of contexts within the 14 pre-2004 countries while maintaining analytical rigor.

fsQCA views empirical cases as configurations of conditions and outcomes, allowing us to examine how different combinations of conditions contribute to pesticide reduction. This method utilizes set theory to consider cases as members of a given set to varying degrees, enabling nuanced analysis through degrees of membership rather than binary categorization. The method assesses relationships between sets in terms of necessity and sufficiency, using Boolean algebra to analyze the presence or absence of conditions and their combinations relative to the occurrence of the outcome. fsQCA's embrace of complex causality aligns well with our goal of understanding the multifaceted influences on pesticide reduction. These features include conjunctural causation, equifinality, and asymmetric causation. Conjunctural causation means that outcomes often result from the interplay of multiple conditions. Rather than isolating single conditions, fsQCA examines how combinations of conditions work together to lead to an outcome. This approach highlights the importance of understanding context-specific interactions, as certain conditions may only be effective when present together with other conditions. Equifinality acknowledges that different combinations of conditions can lead to the same outcome. In the context of our study, multiple pathways might lead to successful pesticide reduction, each involving different sets of conditions. fsQCA allows us to identify these distinct pathways, demonstrating that there is no single formula for achieving policy success. Asymmetric causation recognizes that the presence and absence of an outcome may have different explanations. In other words, the conditions that are conducive to effective pesticide reduction might not simply be the inverse of those that cause failure to reduce pesticides. This aspect of fsQCA helps in understanding the complex and often non-linear nature of policy implementation.

To implement fsQCA, we follow a structured process beginning with calibration, which determines the membership of each case in each set based on predefined criteria. Calibration is crucial as it transforms raw data into fuzzy sets that can be analyzed within the fsQCA approach. We then proceed with necessity analysis to identify necessary conditions for the successful implementation of pesticide reduction policies. Following this, we conduct a sufficiency analysis, which evaluates whether particular combinations of conditions are sufficient to produce the outcome. We interpret the intermediate solution of the QCA analysis, making assumptions about unobserved truth table rows in line with our theoretical expectations (Haesebrouck and Thomann 2021; Rihoux and Ragin 2009). Additionally, we apply the Enhanced Standard Analysis (ESA), excluding contradictory assumptions and contradicting statements of necessity from the truth table (Oana et al. 2022; Bazzan et al. 2022), to produce solutions for successful implementation.[5] To run the analysis, we used R software, version 4.4.1, with the SetMethods package v. 4.0 and QCA package v. 3.22.

QCA provides two key parameters of fit: consistency and coverage. Consistency measures the degree to which cases that share a given condition (or combination of conditions) also share the outcome. In other words, it assesses how uniformly a causal relationship holds across the cases. A high consistency score means that when the causal condition is present, the outcome is also usually present. Coverage assesses the extent to which a causal condition (or combination of conditions) accounts for the instances of an outcome. It provides a measure of empirical relevance or importance of a causal relationship. There are two types of coverage: raw coverage and unique coverage. Raw coverage indicates the proportion of the outcome that is explained by a particular causal condition or combination of conditions. Unique coverage identifies the proportion of the outcome that is exclusively explained by a particular causal condition, not overlapping with other conditions.

Our study utilizes a comprehensive dataset compiled from multiple sources to operationalize the outcome and conditions relevant to pesticide reduction. Key data sources include: the 2022 Eurobarometer on Food Safety in the EU, which provides insights into public opinion on pesticide use and environmental concerns across the 14 pre-2004 countries; policy documents, including legislative texts, implementation reports, and evaluation documents from the European Union, detailing the regulatory framework and member states' implementation of pesticide reduction policies; interest group data from the EU Transparency Register, used to assess the number and capacity of interest groups lobbying on pesticide-related issues, which is crucial for understanding the influence of these groups on policy implementation; Eurostat Data on harmonized risk indicators for pesticides under Directive 2009/128/EC, used to quantify and compare the implementation of pesticide policies across member states.

Calibration involved categorizing each condition and the outcome into fuzzy sets with varying degrees of membership, using a 4-point scale of fuzzy scores (0.00, 0.33, 0.67, and 1.00). The outcome we aim to explain is the successful implementation of EU pesticide reduction policies across member states. We operationalize successful implementation (SIMPL) using Eurostat data, specifically the Harmonized Risk Indicator for pesticides (HRI). This indicator is employed by the European Commission to monitor trends in risk reduction from pesticide use at the EU level and by Member States to track similar trends at the national level. The HRI compares a country's current behavior to its baseline behavior in 2011–2013, where the baseline value is set at 100. A value below 100 indicates improvement compared to the baseline, while a value above 100 indicates deterioration. We utilize HRI data from 2021 for our analysis. To calibrate SIMPL, we assigned membership scores based on HRI values to capture the extent of pesticide reduction implementation. Countries with HRI values less than or equal to 45 were considered fully in (1.00), indicating significant improvements and successful implementation. Countries with HRI values between 45 and 65 were mostly in (0.67), reflecting moderate improvements and moderately successful implementation. Those with HRI values between 65 and 100 were mostly out (0.33), indicating slight improvements or slight deteriorations, representing less successful implementation. Countries with HRI values greater than 100 were fully out (0.00), indicating deteriorations and poor implementation. These scores are anchored in the HRI's baseline methodology and reflect substantive differences in performance.

For the condition high number of interest groups (HNINTG), we used the number of registered interest groups in the EU transparency register. The membership scores were assigned to align with substantive distinctions in lobbying intensity, using natural breaks in the distribution of interest group counts. Countries with fewer than 12 interest groups were fully out (0.00), indicating a likely low lobbying. Countries with 12 to 27 interest groups were more out than in (0.33), reflecting a small number of interest groups and moderate lobbying. Those with 27 to 49 interest groups were more in than out (0.67), indicating moderate lobbying, while countries with more than 49 interest groups were fully in (1.00), indicating high lobbying. These thresholds correspond to key points in the data distribution, with the cutoff for full membership above the 75th percentile, for partial membership between the 50th to 75th percentile, for partial non-membership 25th to 50th percentile, and for full non-membership below the 25th percentile. Regarding the high lobbying capacity of interest groups (HCINTG), we measured lobbying capacity by the number of full-time equivalents (FTEs). Countries with fewer than 10 FTEs were fully out, indicating no capacity to lobby. Those with 10 to 50 FTEs were more out than in, indicating low capacity to lobby. Countries with 50 to 150 FTEs were more in than out, indicating moderate capacity, while those with more than 150 FTEs were fully in, indicating high capacity.

For high public concern (HPUB), we used the percentage of respondents concerned about pesticide residues in their food from the 2022 Eurobarometer on Food Safety in the EU. Countries where less than 32% of respondents selected pesticide residues as their first concern were fully out (0.00). Those who were 32% to 43% of respondents were concerned were more out than in (0.33). Countries where 43% to 50% of respondents were concerned were more in than out (0.67), while those with more than 50% of respondents concerned were fully in (1.00). The thresholds are set in correspondence with the maximum level, just above the median, and in correspondence with the minimum level (in line with Van de Graaf et al. 2018).

GREENSEAT is a condition that we operationalize dichotomously, indicating the presence of green party members in the national parliament. This condition captures the legislative influence green parties can exert, even when not part of the governing coalition.

Table 1 summarizes the operationalization of the outcome and conditions in our study, providing a description of how they are operationalized, the data sources used, and the calibration thresholds applied.

5 | Findings

The analysis of necessity shows that no single condition is to be considered necessary for the outcome to occur, as none exceeds the thresholds of consistency value of 0.9, coverage of 0.6, and relevance of necessity (RoN) of 0.5 (Mello 2022; Schneider and Wagemann 2012).

The analysis of sufficiency reveals that four paths are sufficient for successful implementation to occur (see Table 2). The solution has a consistency value of 0.934. Consistency sufficiency denotes the extent to which cases correspond to the configurational relationship expressed in a solution (Fiss 2011). Overall solution coverage shows that this solution explains > 58% of membership in the positive outcome. While this indicates a substantial understanding of implementation patterns, it also signifies that there are other conditions at play in the remaining cases. Cases explained by this solution are Denmark, Portugal, Greece, Spain, and Italy.

Path 1 is characterized by the combination of the absence of strong lobbying by interest groups, the presence of green party

TABLE 1 | Measurement and calibration.

Outcome/Condition	Operationalization	Data sources	Calibration
Successful Implementation (SIMPL)	HRI values indicating the level of pesticide reduction implementation	Eurostat data, national reports	4-point fuzzy score Fully In (1.00): HRI ≤ 45; Mostly In (0.67): 45 < HRI ≤ 65; Mostly Out (0.33): 65 < HRI ≤ 100; Fully Out (0.00): HRI > 100
High Number of Interest Groups (HNINTG)	Number of interest groups lobbying for pesticide reduction	EU Transparency Register	4-point fuzzy score Fully Out (0.00): < 12; More out than in (0.33): 12 ≤ HNINTG < 27; More in than out (0.67): 27 ≤ HNINTG < 49; Fully In (1.00): ≥ 49
High Capacity of Interest Groups (HCINTG)	Capacity of interest groups measured in Full Time Equivalents (FTEs)	EU Transparency Register	4-point fuzzy score Fully Out (0.00): < 10 FTEs; More out than in (0.33): 10 ≤ FTEs < 50; More in than out (0.67): 50 ≤ FTEs < 150; Fully In (1.00): ≥ 150 FTEs
High Public Concern (HPUB)	Percentage of respondents concerned about pesticide residues in their food	Eurobarometer surveys	4-point fuzzy score Fully Out (0.00): < 32% concerned; More out than in (0.33): 32% ≤ HPUB < 43% concerned; More in than out (0.67): 43% ≤ HPUB < 50% concerned; Fully In (1.00): ≥ 50% concerned
Green Party seated in Parliament (GREENSEAT)	Presence of a Green Party in Parliament	Institutional websites	Crisp condition, either present (1) or absent (0)

TABLE 2 | Analysis of sufficiency.

	Configurations				Overall solution
	1	2	3	4	
Green party seating in Parliament (GREENSEAT)	●		●	⊖	
Strong Public Concern towards Pesticides (HPUB)	●	●	●	⊖	
High Capacity of Interest Groups (HCINTG)		●	●	●	
High Number of Interest Groups (HNINTG)	⊖	⊖		●	
Consistency	0.876	1.0	1.0	1.0	0.934
PRI	0.754	1.0	1.0	1.0	0.877
Raw coverage	0.291	0.248	0.289	0.084	0.582
Unique coverage	0.126	0.084	0.125	0.084	
Cases	DEN, POR	GRE	SPA	ITA	

Note: ●, condition present; ⊖, condition absent; empty cell, condition irrelevant (see Rubinson et al. 2019).

representation in parliament, and high public concern about pesticide residues (~HNINTG*GREENSEAT*HPUB). In this scenario, high public concern and green party representation in parliament act together as sufficient conditions to drive the successful implementation of pesticide reduction policies, even without strong interest group lobbying. The literature suggests that critical levels of public concern can pressure policymakers to act, particularly when aligned with green political representation that provides a platform for advocating environmental policies (Bazzan and Migliorati 2020; Rauh 2019). This path illustrates that public opinion and green political advocacy can create momentum for policy change, even in the absence of strong interest group involvement. In Denmark, high public concern about pesticide residues, often linked to strong environmental awareness, provided significant pressure on policymakers. This was amplified by green party representation (with the Red-Green Alliance holding 14 seats and the Alternative—now Independent Greens—holding 9 seats), which played a key role in channeling public concerns into actionable policies. Similarly, in Portugal, green political advocacy found fertile ground in a public sphere increasingly attentive to environmental health issues, even in the relative absence of strong lobbying by interest groups. These cases illustrate how green political presence and public opinion can effectively catalyze policy change, demonstrating the capacity of public concern to substitute for direct lobbying when green parties are involved.

Path 2 presents a different dynamic, where the absence of strong lobbying by interest groups combines with high-capacity interest groups lobbying against pesticides and high public concern (~HNINTG*HCINTG*HPUB). This path demonstrates that the capacity of a few well-organized interest groups, coupled with strong public concern, is sufficient to drive successful policy implementation, even in the absence of widespread lobbying. Resource mobilization theory supports this finding, highlighting how well-resourced interest groups can influence policy by providing technical expertise, research, and advocacy (Klüver 2010, 2012; Klüver et al. 2015; Rasch 2018). This path underscores that focused, high-capacity lobbying and public support can overcome the lack of broad interest group involvement. Greece exemplifies this dynamic, where public concern about pesticides is notably high—69% of respondents express worry about pesticide residues—but the overall number of interest groups remains relatively low, with only 12 active groups. Despite their small number, these interest groups exhibit substantial lobbying capacity, employing over 52 full-time equivalents (FTEs), which allows them to exert considerable influence.

Path 3 emphasizes the conjunctural effect of green party representation in parliament, high-capacity interest groups, and high public concern (GREENSEAT*HCINTG*HPUB). In this scenario, these three factors combine to create a powerful coalition for pesticide reduction policies. Green party seats in parliament offer a political platform for pushing environmental agendas, while high-capacity interest groups provide resources and expertise, and high public concern generates pressure on policymakers. This path aligns with theories of coalition-building and policy advocacy, where diverse actors collaborate to achieve shared goals (Daugbjerg and Feindt 2019; Michalowitz 2007; Feindt 2018; De Bruycker 2017). The conjunctural presence of these conditions demonstrates their combined ability to effectively drive policy implementation. In Spain, the green party Equo (now integrated into the left-wing coalition Unidas Podemos) has been a strong advocate for environmental policies, including pesticide reduction. High-capacity interest groups, equipped with substantial resources and expertise, collaborated with these political actors to develop and advocate for effective policy measures. Additionally, high public concern about pesticide residues added pressure on policymakers, reinforcing the coalition's efforts. This case illustrates how diverse actors—political, societal, and technical—can align their interests to achieve successful policy implementation.

Path 4 highlights a scenario where the presence of strong interest group lobbying, the absence of green party representation in parliament, high-capacity interest groups, and low public concern together drive policy implementation (HNINTG*~GREENSEAT*HCINTG*~HPUB). This path reveals that, in the absence of public concern or green political advocacy, the capacity and strength of interest groups can independently drive successful implementation. Strong lobbying efforts by interest groups and their ability to mobilize resources provide policymakers with the information and support needed to enforce pesticide reduction policies, even without public pressure or green political backing. Italy lacks a significant green party presence in Parliament, and public concern about pesticide residues is relatively low, as evidenced by Eurobarometer surveys showing less urgency about environmental health risks compared to other countries. Despite these limitations, strong and well-resourced interest groups have been instrumental in driving policy change. For instance, Legambiente is one of Italy's most prominent environmental organizations. Known for its advocacy on various environmental issues, including sustainable agriculture, pesticide reduction is a core focus of its agenda. Their well-established reputation and network allowed them to engage effectively with policymakers, providing expertise, organizing public campaigns, and lobbying for stricter regulations. Italy's case highlights the critical role of strong interest group lobbying in contexts where public and political support for environmental issues is limited. This finding aligns with resource mobilization theory, emphasizing the role of interest groups in policy-making processes (Klüver 2010, 2012).

In summary, the Enhanced Standard Analysis identifies four distinct paths to achieving successful pesticide reduction:

- Public Concern and Green Political Representation Compensating for Weak Lobbying: The combination of high public concern and green party representation in parliament can drive successful policy implementation, even in the absence of strong lobbying by interest groups. This highlights the power of public opinion and political advocacy in shaping environmental policies.
- Public Concern and High-Capacity Interest Groups as Drivers of Change: High public concern, combined with the capacity of well-organized interest groups, is sufficient to push for pesticide reduction policies, even when broad lobbying efforts are absent. This underscores the importance of targeted, resourceful lobbying efforts supported by public pressure.
- Coalition of Public Concern, Green Party Representation, and Interest Groups: A conjunctural effect emerges when high-capacity interest groups, Green Party representation in parliament, and high public concern align, forming a powerful coalition that effectively drives policy implementation. This path demonstrates the strength of collaboration among multiple actors.
- Interest Group Strength Compensating for Low Public and Political Support: In contexts where public concern and green political representation are weak, the strength and capacity of organized interest groups alone can drive successful pesticide reduction. This highlights the critical role of well-resourced lobbying efforts in policymaking, even in less supportive environments.

These paths highlight different strategies for achieving pesticide reduction goals, emphasizing the significance of public opinion, interest group capacity, and political representation in various combinations. These insights can guide policymakers and advocates in designing effective interventions to promote effective pesticide reduction policies.

Our expectations were further examined. The anticipated influence of a high number of interest groups (HNINTG) on policy implementation was supported in Path 4, but the absence of a high number of interest groups (~HNINTG) appeared in Paths 1 and 2. High-capacity interest groups (HCINTG) positively impacted policy implementation, as seen in Paths 2, 3, and 4. Green party seats in parliament (GREENSEAT), combined with other conditions, did influence policy implementation in Paths 1 and 3, but their absence appeared in Path 4. High public concern (HPUB) was effective in Paths 1, 2, and 3, while absent in Path 4.

6 | Discussion and Conclusion

Pesticides remain a critical topic in sustainability debates due to their widespread use in global agriculture and their well-documented detrimental effects on ecosystems, biodiversity, and human health. Despite efforts to mitigate pesticide use by the EU, the flexibility accredited to member states in implementing these measures has led to significant variation in outcomes. The challenges of aligning EU-level law with diverse domestic political and institutional contexts are compounded by resistance from powerful stakeholders, as illustrated by the recent failure to adopt binding pesticide reduction targets. This study applied the framework of Differentiated Policy Implementation (DPI) to analyze the conditions conducive to effective pesticide reduction across EU member states. Our findings underscore the importance of understanding the interplay between political dynamics, institutional capacities, and public engagement in addressing the complex issue of pesticide reduction within the EU.

Our analysis of sufficiency revealed four distinct pathways to implementation of pesticide reduction policies, each highlighting different combinations of causal conditions. The findings contribute to our understanding of policy implementation dynamics in environmental governance, particularly in the context of pesticide regulation on the one hand. On the other hand, our results complement the literature on Differentiated Policy Implementation (DPI) by providing empirical evidence on how different combinations of public opinion, interest group capacity, and political representation influence pesticide reduction policy implementation. We demonstrate how specific combinations of political and societal conditions lead to differentiated policy implementation. This empirical evidence underscores the importance of considering the practical application and discretion exercised by member states, thus contributing to a more comprehensive understanding of EU policy implementation dynamics.

Interestingly, the analysis challenges an initial expectation, namely concerning the number of interest groups. The findings show that the number of interest groups is less influential than their capacity, suggesting that the quality of advocacy may be more important than quantity in affecting policy implementation.

This analysis is subject to some limitations. An important point that we would like to mention is the conceptualization of the outcome, i.e., the successful implementation of pesticide reduction policies. As explained in the section on research design, we use the Harmonized Risk Indicator (HRI) for pesticides. The HRI compares a country's pesticide sales in 2021 to pesticide sales in 2011–2013. While this renders all countries directly comparable, the HRI bears the disadvantage of being a policy outcome measure[6] instead of a direct implementation measure (Cairney 2012, 33). Hence, we cannot rule out the possibility that conditions other than public action contributed to these numbers, such as farmers reducing pesticide purchases based on their own accord.

Another limitation is the confinement of the analysis to the 14 pre-2004 countries. As mentioned in the research design section, this choice was motivated on the one hand by manageability and on the other hand by the fact that these countries were subjected to EU pesticide reduction policies from the outset, with a first directive on plant protection products adopted as early as 1991 (91/414/EEC). Nevertheless, increasing the study's scope to the European Union would obviously be a worthwhile endeavor for future research. Future research could transfer the findings to other EU member states and additionally to comparative studies across different policy domains in order to test the generalizability of these findings beyond the specific case of pesticide regulation.

Conflicts of Interest

The authors declare no conflicts of interest.

Endnotes

[1] Full title: Regulation (EC) No. 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC.

[2] Full title: Regulation (EC) No. 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC Text with EEA relevance.

[3] Full title: Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides (Text with EEA relevance).

[4] The 14 countries are: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and Sweden.

[5] Enhanced Standard Analysis in QCA differs from the Standard Analysis in how it handles logical remainders and counterfactual assumptions. Logical remainders are combinations of conditions that are logically possible but lack empirical evidence in the dataset. The Standard Analysis includes some of these remainders as simplifying assumptions to achieve parsimonious solutions, but this can lead to what are known as untenable assumptions. These occur when assumptions about logical remainders contradict formal logic, common sense, or theoretical expectations. ESA avoids using remainders that would result in untenable assumptions by explicitly excluding them from the logical minimization process. This approach ensures that the solution terms align with both theoretical expectations and logical coherence, distinguishing ESA from the Standard Analysis.

[6] To avoid confusion, we would like to highlight the terminological overlap between QCA terminology, where "outcome" denotes the method's phenomenon of interest (Schneider and Wagemann 2012), and policy evaluation terminology, where "outcome" denotes a policy's societal effects (Dal Mas et al. 2019). While in the rest of this paper, we have used the term "outcome" exclusively in a QCA context, here, we refer to the outcome in the context of policy evaluation.

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Appendix A

Raw Data, Calibrated Data & Outputs of the Analyses

Table A1 presents the raw data.

TABLE A1 | Raw data.

ID	HNINTG	HCINTG	GREENSEAT	HPUB	SIMPL
BEL	182	675.2	1	40	47
DEN	15	10.8	1	50	56
GER	118	256.1	1	43	73
IRE	14	27.1	1	36	52
GRE	12	52.5	0	69	43
SPA	49	97	1	46	65
FRA	71	137	0	51	68
ITA	36	69	0	31	56
LUX	1	0.1	1	43	36
NET	75	148.8	1	31	55
AUS	27	23.6	1	32	124
POR	11	18.9	1	50	60
FIN	8	3.4	1	40	115
SWE	27	49.3	1	29	61

The calibrated data are presented in Table A2.

TABLE A2 | Calibrated data.

ID	HNINTG	HCINTG	GREENSEAT	HPUB	SIMPL
BEL	1	1	1	0.33	0.67
DEN	0.33	0.33	1	0.67	0.67
GER	1	1	1	0.33	0.33
IRE	0.33	0.33	1	0.33	0.67
GRE	0.33	0.67	0	1	1
SPA	0.67	0.67	1	0.67	0.67
FRA	1	0.67	0	1	0.33
ITA	0.67	0.67	0	0	0.67
LUX	0	0	1	0.33	1
NET	1	0.67	1	0	0.67
AUS	0.67	0.33	1	0	0
POR	0.33	0.33	1	0.67	0.67
FIN	0.33	0	1	0.33	0
SWE	0.67	0.33	1	0	0.67

Table A3 presents the analysis of the necessity for successful implementation.

TABLE A3 | Analysis of necessity.

	Cons.Nec	Cov.Nec	RoN
HCINTG	0.665	0.761	0.807
GREENSEAT	0.751	0.547	0.376
HNINTG	0.665	0.640	0.654
HPUB	0.581	0.823	0.893
~HCINTG	0.665	0.761	0.807
~GREENSEAT	0.249	0.667	0.917
~HNINTG	0.582	0.824	0.893
~HPUB	0.666	0.640	0.654

Note: Thresholds for consistency necessity > 0.9; coverage necessity > 0.6; relevance of necessity > 0.5.

Table A4 presents the analysis of necessity for unsuccessful implementation (~SIMPL).

TABLE A4 | Analysis of necessity for ~SIMPL.

	Cons.Nec	Cov.Nec	RoN
HCINTG	0.665	0.761	0.807
GREENSEAT	0.751	0.547	0.376
HNINTG	0.665	0.640	0.654
HPUB	0.581	0.823	0.893
~HCINTG	0.665	0.761	0.807
~GREENSEAT	0.249	0.667	0.917
~HNINTG	0.582	0.824	0.893
~HPUB	0.666	0.640	0.65

Note: Thresholds for consistency necessity > 0.9; coverage necessity > 0.6; relevance of necessity > 0.5.

Refer to Table A5 for the enhanced truth table for successful implementation.

TABLE A5 | Enhanced truth table for SIMPL.

	HCINTG	GREENSEAT	HNINTG	HPUB	OUT	*n*	Incl	PRI	Cases
10	1	0	0	1	1	1	1.000	1.000	GRE
11	1	0	1	0	1	1	1.000	1.000	ITA
16	1	1	1	1	1	1	1.000	1.000	SPA
6	0	1	0	1	1	2	0.876	0.754	DEN, POR
15	1	1	1	0	0	3	0.832	0.504	BEL, GER, NET
5	0	1	0	0	0	3	0.727	0.502	IRE, LUX, FIN
7	0	1	1	0	0	2	0.699	0.254	AUS, SWE
12	1	0	1	1	0	1	0.660	0.493	FRA
1	0	0	0	0	?	0	—	—	
2	0	0	0	1	?	0	—	—	
3	0	0	1	0	0	0	—	—	
4	0	0	1	1	?	0	—	—	
8	0	1	1	1	0	0	—	—	
9	1	0	0	0	?	0	—	—	
13	1	1	0	0	?	0	—	—	
14	1	1	0	1	?	0	—	—	

Note: Thresholds for consistency sufficiency > 0.75 (we set 0.75); PRI > 0.5. ? indicates a logical remainder — a logically possible but unobserved configuration for which no outcome can be empirically assigned.

Table A6 presents the enhanced parsimonious solution for successful implementation.

TABLE A6 | Enhanced parsimonious solution for SIMPL.

```
M1: ~HNINTG*HPUB + HCINTG*~GREENSEAT*~HPUB + HCINTG*GREENSEAT*HPUB -> SIMPL

                              inclS   PRI    covS    covU    cases
----------------------------------------------------------------------
1               ~HNINTG*HPUB  0.901  0.836  0.374  0.209  DEN,POR; GRE
2   HCINTG*~GREENSEAT*~HPUB  1.000  1.000  0.084  0.084  ITA
3     HCINTG*GREENSEAT*HPUB  1.000  1.000  0.289  0.125  SPA
----------------------------------------------------------------------
                          M1  0.934  0.877  0.582
```

Note: Thresholds for consistency sufficiency > 0.75 (we set 0.75); PRI > 0.5. > 58% of cases is explained by the solution (coverage).

Visualize the sufficiency plot in Figure A1 illustrating the intermediate enhanced solution for successful implementation.

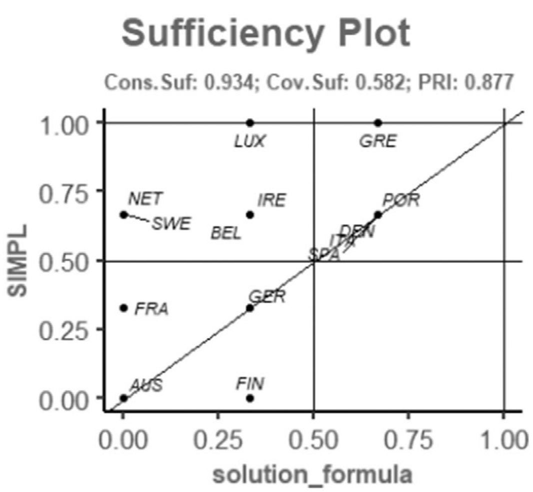

FIGURE A1 | Sufficiency plot intermediate enhanced solution for SIMPL.

Refer to Table A7 for the enhanced truth table for the unsuccessful implementation.

TABLE A7 | Enhanced truth table for unsuccessful implementation (~SIMPL).

Row	HCINTG	GREENSEAT	HNINTG	HPUB	OUT	*n*	Incl	PRI	Cases
7	0	1	1	0	1	2	0.898	0.746	AUS, SWE
16	1	1	1	1	0	1	0.853	0.000	SPA
15	1	1	1	0	0	3	0.830	0.496	BEL, GER, NET
5	0	1	0	0	0	3	0.724	0.498	IRE, LUX, FIN
12	1	0	1	1	0	1	0.670	0.507	FRA
6	0	1	0	1	0	2	0.620	0.246	DEN, POR
11	1	0	1	0	0	1	0.493	0.000	ITA
10	1	0	0	1	0	1	0.000	0.000	GRE
1	0	0	0	0	0	0	—	—	
2	0	0	0	1	0	0	—	—	
3	0	0	1	0	0	0	—	—	
4	0	0	1	1	0	0	—	—	
8	0	1	1	1	0	0	—	—	
9	1	0	0	0	0	0	—	—	
13	1	1	0	0	?	0	—	—	
14	1	1	0	1	?	0	—	—	

Note: Thresholds for consistency sufficiency > 0.75 (we set 0.75); PRI > 0.5. ? indicates a logical remainder — a logically possible but unobserved configuration for which no outcome can be empirically assigned.

Table A8 presents the enhanced parsimonious solution for unsuccessful implementation (~SIMPL).

TABLE A8 | Enhanced parsimonious solution for ~SIMPL.

```
M1: ~HCINTG*GREENSEAT*HNINTG*~HPUB -> ~SIMPL

                                  inclS   PRI   covS   covU   cases
--------------------------------------------------------------------
1  ~HCINTG*GREENSEAT*HNINTG*~HPUB  0.898  0.746  0.498    -    AUS,SWE
--------------------------------------------------------------------
                               M1  0.898  0.746  0.498
```

Note: Thresholds for consistency sufficiency > 0.75 (we set 0.75); PRI > 0.5.

Table A9 presents the enhanced intermediate solution for unsuccessful implementation (~SIMPL).

TABLE A9 | Enhanced intermediate solution for ~SIMPL.

```
M1:    ~HCINTG*GREENSEAT*HNINTG*~HPUB -> ~SIMPL

                                  inclS   PRI   covS   covU   cases
--------------------------------------------------------------------
1  ~HCINTG*GREENSEAT*HNINTG*~HPUB  0.898  0.746  0.498    -    AUS,SWE
--------------------------------------------------------------------
                               M1  0.898  0.746  0.498
```

Note: Thresholds for consistency sufficiency > 0.75 (we set 0.75); PRI > 0.5.

Fit-Oriented Robustness Tests Outcome SIMPL

To assess the robustness of our findings, we applied the QCA robustness test protocol as outlined by Oana et al. (2022). This protocol includes three main types of robustness tests: sensitivity ranges, fit-oriented robustness, and case-oriented robustness. For our analysis, we first produced the initial enhanced intermediate solution (IS) and two alternative solutions (test solutions TS1 and TS2), each incorporating modifications to the analytic decisions made in the IS. The protocol advocates for calculating the sensitivity ranges of key parameters such as raw consistency thresholds and frequency cuts. This ensures that the solution remains consistent within a defined range of these parameters. In our case, this allowed us to determine whether our findings held across a variety of plausible alternative thresholds. In alternative test solution 1 (see Table A10), we raise the raw consistency threshold from 0.75 to 0.8; in test solution 2 (see Table A11), we raise the frequency cut from one case to two cases.

TABLE A10 | Test solution TS1.

```
From C1P1:

M1:    HCINTG*GREENSEAT*HPUB + HCINTG*~HNINTG*HPUB + GREENSEAT*~HNINTG*HPUB
+
       HCINTG*~GREENSEAT*HNINTG*~HPUB -> SIMPL

                                    inclS   PRI   covS   covU   cases
----------------------------------------------------------------------
1           HCINTG*GREENSEAT*HPUB   1.000  1.000  0.289  0.125  SPA
2             HCINTG*~HNINTG*HPUB   1.000  1.000  0.248  0.084  GRE
3          GREENSEAT*~HNINTG*HPUB   0.876  0.754  0.291  0.126  DEN,POR
4  HCINTG*~GREENSEAT*HNINTG*~HPUB   1.000  1.000  0.084  0.084  ITA
----------------------------------------------------------------------
                               M1   0.934  0.877  0.582
```

TABLE A11 | Test solution TS2.

```
M1:    GREENSEAT*~HNINTG*HPUB -> SIMPL

                            inclS   PRI   covS   covU   cases
--------------------------------------------------------------
1  GREENSEAT*~HNINTG*HPUB   0.876  0.754  0.291   -    DEN,POR
--------------------------------------------------------------
                       M1   0.876  0.754  0.291
```

The robust core (RC) is defined as the overlap between the initial solution (IS) and the minimal test set (minTS), and it provides insight into the core consistency of the solution across all robustness tests. The consistency and coverage of the RC are calculated as follows:

Cons.Suf	Cov.Suf	PRI
0.876	0.291	0.754

These values indicate that the RC maintains a high degree of consistency but a low level of coverage, suggesting that while the core of the solution is robust, it applies to a narrower range of cases.

Finally, we calculate the robustness fit RF parameters:

	RF_cov	RF_cons	RF_SC_minTS	RF_SC_maxTS
Robustness_Fit	0.5	1.066	0.532	1

These parameters show that while the consistency between IS and the RC is high (RF_cons = 1.066), the coverage (RF_cov = 0.5) is relatively low, indicating a modest degree of overlap between IS and the RC. The robustness fit for both the minimum test set (RF_SC_minTS = 0.532) and the maximum test set (RF_SC_maxTS = 1) further supports this interpretation, highlighting the degree of variation across alternative solutions.

Case-Oriented Robustness Tests Outcome SIMPLFS

Eventually, the fit-oriented robustness tests are complemented with a case-oriented perspective (Oana et al. 2022). The case-oriented robustness tests, as outlined by Oana et al. (2022), are essential for identifying how individual cases are classified under alternative solutions (minTS and maxTS). The robustness plot (Figure A2) highlights the distribution of cases in different quadrants:

- Diagonal Cases: A few cases are located on the diagonal, indicating a moderate overlap across the three solutions (IS, minTS, and maxTS), which is consistent with a low degree of overlap between solutions.
- Lower-Right Quadrant: Three cases are found in this quadrant, indicating "shaky" typical and "shaky deviant" consistency cases. These cases are weakly consistent and might shift when the solution parameters change.
- Rob_Case_Rank: The presence of cases in the lower-right quadrant leads to a low Rob_Case_Rank of 3, signifying that the initial solution includes shaky typical and shaky deviant consistency cases, reflecting a modest overall robustness.
- RCR_typ (Typical Cases Robustness): The RCR_typ value of 0.4 indicates that 40% of typical cases are robust, meaning that only 40% of the typical cases are part of both IS and minTS, while the rest could shift depending on analytic decisions.

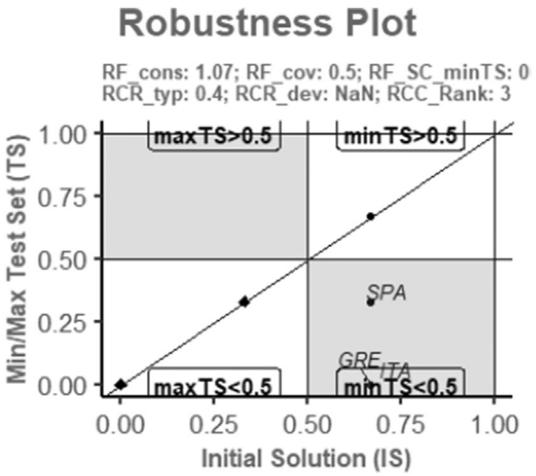

FIGURE A2 | Case-oriented robustness plot.